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THE INFLUENCE OF DEFORMATION RATE UPON RESISTANCE DURING PLASTIC DEFORMATION

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[Figures referred to herein are appended.]

Processing metals by compression (rolling and milling) is characterized by variable rates of deformation, which have not been thoroughly investigated. An attempt is made in this article to explain one effect which takes place during a variable deformation rate.

Let a prism of height Zmm be compressed between plates of a press at the rate of v mm/sec. The rate of deformation will then equal

$$\lambda = \frac{\frac{z-z'}{z}}{t-t'} = \frac{\Delta z}{z\Delta t} = \frac{v}{z}. \qquad (1)$$

This equation can also be extended to other compressive processes since these can be considered to be composed contractions (or expansions) of various prisms into which any solid undergoing transformation may be theoretically broken up.

The approximate relation between deformation rate and resistance during plastic deformation is shown in Figure 1. Resistance grows with increase in rate and asymptotically approaches a certain maximum.

There is not much experimental data to establish the exact relation, but it can be reliably accepted that the indicated maximum resistance during "hot" deformations is two or three times greater than the initial resistance, which is observed at deformation rates close to zero.

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In rolling iron, forging, and die stamping, the deformation rate varies from several thousand percent a second at the beginning to zero at the end of deformation. Quite an important problem appears: namely, how to compute this variable rate during the determination of resistance.

The theory of processing metals by compression usually assumes that there is a close connection between deformation rate and resistance and that the resistance drops with the decrease in rate in accordance with the approximate relationship graphed in Figure 1. Therefore, the determination of resistance involves the question of average deformation rates. Because the final rate always equals zero, this average is approximately half the initial rate, if in the first approximation the deformation rate is assumed to diminish linearly.

It seems to us that this point of view is not completely accurate, for the reason that the time of stay of the metal in the deformed state is so short that the resistance cannot decrease to the same extent as the deformation rate.

For the explanation of this we shall examine the graph in Figure 2, which shows the contraction of a small cylinder of alloyed lead and antimony in a press which can quickly stop and start again. (The duration of the stops grows successively shorter.) After each stop, the deformation rate equals zero; the resistance increases rapidly at first, and then more and more slowly. This phenomenon is known as "relaxation" and is caused by the fact that plastic deformation decreases, since it takes place at the expense of elastic deformation after press stoppage. Resistance is proportional to elastic deformation and decreases in proportion to decrease of the latter.

This "internal" deformation is no different in principle from ordinary deformation, but the outer dimensions of the cylinder remain unchanged, and according to the accepted definition of deformation rate (1), the deformation rate is equal to zero. The relaxation rate is measured by the decrease in resistance per second; from this point of view it represents an essentially new quantity which is dependent only upon the "excess" elastic deformation and is not connected with the change in form of the solid. We shall note, by the way, that the excess elastic deformation depends not only upon the mechanical properties of deformed metal, but also upon the hardness of the machine, although this condition does not influence greatly our line of reasoning here.

The shorter the duration of press stoppage, the less the relaxation action can develop and the less the resistance decreases; in the optimum case, where the press stops just for one instant, resistance would not be able to decrease at all, although the deformation rate would equal zero.

If, instead of fully stopping the press, we suddenly decrease its rate, then the described characteristic of the phenomenon is preserved: after the rate is decreased, the resistance will begin to fall and strive to attain the value corresponding to the new lower deformation rate. This value will be attained only if the duration of the press movement at the decreased rate is sufficiently great so that the excess of stress (elastic deformation) will be absorbed at the expense of relaxation. Reversely, a decrease in resistance will be obtained which becomes smaller the shorter the time of change in the press, as shown in Figure 3.

If we go still further and replace the instantaneous change of rate by a gradual rate and consider it as succession of many instantaneous changes, then we will reach the following conclusion: In order for a fixed relation to exist between deformation rate and resistance, the rate of decrease of the rate must be lower than or equal to the relaxation rate.

The matter is entirely different during increase in rate. Figure 2 shows that resistance grows gradually with increase in rate (the starting of the press); however, this is not caused by the softening of the metal during the stopping of the press. After the starting of the press, the deformation rate immediately

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reaches its previous value and at once a close relation is established between rate and resistance, which increases only due to the hardening taking place. In order to satisfy ourselves that this is so, let us see the difference between the phenomenon observed during decreasing rates and that during increasing rates.

The press plates, during contraction, are able only to come together; therefore, once elastic deformation (and the stress which is proportional to it) appears, it can be decreased only at the expense of relaxation, for which a definite time is required. Increase in elastic deformations between the converging press plates is possible and takes place almost instantaneously. If the rate is increased, then resistance increases, and immediately a relation between rate and resistance is established, as only a second is needed for creating a supplementary elastic deformation.

It is difficult to evaluate to what extent the resistance can decrease during forging or iron rolling. The duration of these processes, as can be easily verified by calculation, amounts to some tenths or hundredths of a second. On the other hand, due to the enormous change in rate, the excess stress obtained is quite considerable and the relaxation rate is very high. This problem can only be solved by tests on a high-speed press, which permits a change in rate during one stroke, i.e., to obtain a diagram similar to that shown in Figure 3. Neither the construction of such a press nor the measurement of the stress appearing during it is technically difficult at this time.

The experimental solution of this problem is a matter of great importance. If a decrease in resistance is insignificant, and this appears to be quite probable, then the resistance during forging and iron rolling is most accurately obtained from the initial rate of deformation. These initial rates are quite high (from 10,000 to 30,000 per second), and, as can be seen from Figure 1, they give approximately the same value of resistance close to the maximum. In such a case, the factor of variable rate is excluded from the calculations in determining resistance, and thus the calculations of technological processes become greatly simplified.

/Appended figures follow./

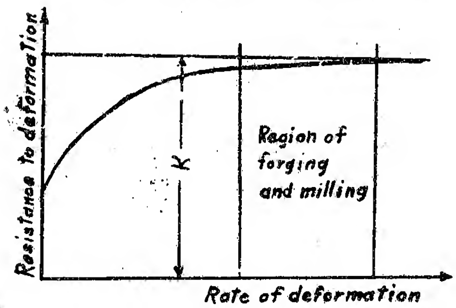

Figure 1

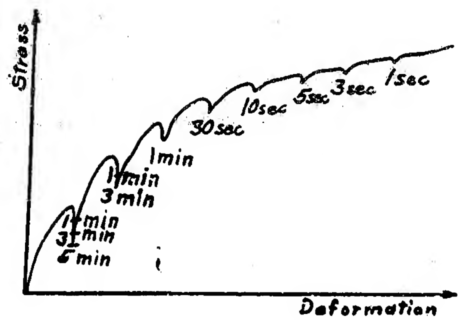

Figure 2

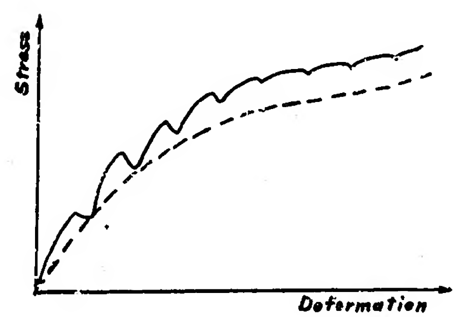

Figure 3